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REPORTS OF OBSERVATORIES.

Lick Astronomical Department,
Lick Observatory, Mt. Hamilton,
July 1, 1910.

To the President of the University of California.

Sir: I have the honor to submit herewith my fifth biennial report, covering the period July 1, 1908, to July 1, 1910.

Volume VIII, Publications of the Lick Observatory, containing seventy-one heliogravure full-page reproductions of Director Keeler's photographs of nebulæ as obtained with the Crossley reflector, as well as a list of 744 nebulæ discovered from the original negatives, was mailed to our correspondents in December, 1908. The reproductions were satisfactory in the main, and it is believed that they set a new standard of excellence. The work was well received by astronomers.

The financial difficulties connected with the publication of our results are well illustrated in the history of this volume. It was necessary to raise funds for this purpose by serious and prolonged personal effort. Beginning in 1902, private subscriptions were received amounting, in 1904, to approximately $2,400. The State Board of Examiners and the State Printer in 1904 authorized the transfer to this purpose of approximately $3,900 from special funds in the resources of the State Printing Office. Advancing prices during the years when the heliogravure reproductions were in progress added substantially to the original estimates of cost, and these advances were met from successive annual budgets of the observatory. The last bill was paid in the spring of 1910, the financial operations of issuing one volume having extended through eight years.

Upon the completion of the Keeler volume, it was hoped that we could proceed promptly with the reproduction of our splendid and unique series of solar coronas, coronal, and chromospheric spectra, etc., as illustrations for a proposed volume to contain the results of the Phœbe A. Hearst Eclipse Expedition to Chile and of the Crocker Eclipse Expeditions to India, Georgia, Sumatra, Egypt, Spain, and Flint Island. A State appropriation for this purpose was requested by the Board of Regents and favorably reported upon by the last Legislature, but the appropriation was not made effective.

The publication of Professor BARNARD'S photographs of the Milky Way and comets obtained on Mount Hamilton in the years 1890-95, referred to in my last report, has made some progress in the biennial period. Professor BARNARD is hopeful that the reproductions will be completed in the coming winter. Funds for this purpose were collected by Professor BARNARD from generous friends in California before his resignation from the Lick Observatory staff in 1895.

The number of *Lick Observatory Bulletins* issued to date is 182, extending into Volume VI. The increased cost of printing renders it impossible to avoid annual deficits in the special fund appropriated for this purpose. Exceedingly regrettable delays in the issuance of *Bulletins* now and then are apparently unavoidable, owing to limited facilities in the university printing-office. For example: In the publication of *Bulletin* No. 181 more than sixty days passed between the sending of the manuscript to the University Press and the supplying of first proof sheets; about seventy days passed between our returning of the first proofs and our receipt of the second proofs; and another delay ensued before the *Bulletin* went to press. Altogether the publication of this *Bulletin* consumed five months.

It is with deep regret that we record the lamented death of DARIUS OGDEN MILLS, former Regent of the University, member of Mr. LICK'S first board of trustees for the Lick Observatory, and donor of the D. O. Mills Expedition to the southern hemisphere, as well as of two Mills spectrographs at Mount Hamilton. His interest in the spectrographic work, for which he made provision, was intellectual as well as financial. A year and a half before the date of his death, the observations secured during the first period of the D. O. Mills Expedition by Professor WRIGHT were ready in manuscript form for publication. Mr. MILLS'S inquiries evinced interest in these results, and hopes were extended to him from time to time that they would be published. Uncertainties as to whether and when the State Printing Office could undertake the work—uncertainties over which I had no control—delayed the publication from time to time until it was too late for Mr. MILLS to see the completed volume. My estimate of the expense of the D. O. Mills Expedition had contained no item to provide for publication, for our results in the past, obtained on Mount Hamilton or on the Hearst and Crocker eclipse expeditions, had been published by the State printer without question, and there was no reason to foresee that this method would fail in the case referred to. After nearly two years of unresolved uncertainty, and shortly after Mr. MILLS's death, the unfortunate delay was mentioned to Mrs. HEARST, Regent of the University of California, and she most generously and with the most unselfish of good wishes to all concerned made private provision for publishing the results by the University Press. Her gift will be available in a few weeks, and it is hoped that the printed results will be ready for distribution soon.

Regrets have been expressed by many astronomers, orally, in letters and in print, that these results should be so tardily made available; but uncertainties over which I had no control prevented publication in the usual channels, and also prevented efforts to secure private funds for the purpose. This explanation seems essential.

It will have appeared that our publication problems have been troublesome and discouraging, with consequences which may be more than regrettable. In the abstract, it must be an unwise policy which locks up the results of extensive investigations.

A grant of four thousand dollars was made by the Carnegie Institution of Washington in 1908, in continuation of similar grants in earlier years, for the employment of assistants and computers. On this foundation the following Carnegie assistants have been employed: Miss A. M. HOBE, July 1, 1908, to July 1, 1910; Miss L. B. ALLEN, July 1, 1908, to July 25, 1909; Mr. KEIVIN BURNS, June 1, 1909, to November 1, 1909; Mr. KRISTIAN LOWS, October 1, 1909, to May 1, 1910.

A few computers have also been employed on this foundation in piece work. These resources have been devoted almost exclusively during the biennial period to the measurement and reduction of spectrograms for determining the radial velocities of stars. Acknowledgments of this assistance are gratefully made.

Early in 1909 the Regents of the university generously appropriated the sum of ten thousand dollars to complete the fire-proof building, with safe storage vaults to contain our collection of celestial photographs, and rooms suitable for the various requirements of photographic research. The building was finished in the spring of 1910, the appropriation having permitted the carrying out of the original plans, with the addition of a few desirable improvements. Several of the rooms are in use, and it is planned to transfer all the photographs, all the records, and all unused parts of instruments, in the latter part of the present year, after the concrete walls shall have been thoroughly dried out by the summer weather.

The seismographic installation, generously provided by Honorable WILLIAM R. HEARST, has been received. A special concrete room has been constructed in the basement of the meridian circle, with appropriate approaches, and the instruments will be erected and used before the close of the present year. The purchases had been delayed, in accordance with the advice of experienced seismologists, in order to receive the benefit of pending improvements in the instruments.

It has been my ambition to make the library of the observatory as complete as possible in all departments closely related to the lines of research undertaken here, and to have it include the more important available works on the history of astronomy. The President and Regents of the university gave generous expression to their approval of this policy by appropriating the sum of two thousand dollars for additions to the library, early in the year 1910.

The Crossley reflector, in common with other similar instruments, was designed to follow the subject under photographic observation not only approximately by means of the excellent driving clock, but accurately by delicate motions given directly to the small plate holder carriage. This is the best known plan for following the so-called fixed objects. In order to utilize this powerful instrument in securing large-scale photographs of objects which move rapidly amongst the stars,—of comets, for example, and especially of Halley's Comet,—it was necessary to arrange to give delicate slow motion to the entire instrument, in right ascension and declination. This involved the installation of anti-friction bearings for the two ends of the polar axis and for the two supports of the declination axis, and of two end-thrust bearings for the declination axis. The instrument was dismounted in January, 1910, while the large castings were taken to San Jose for turning out to receive the roller axis bearings and the end-thrust ball bearings, which had been constructed previously. The instrument was out of commission only ten days. These improvements have been very successful. Though the moving parts of the telescope weigh about six tons, a pull of four pounds on the end of the tube is sufficient to move the telescope in declination, and a pull of eleven pounds moves it in right ascension.

At the same time, a guiding telescope of aperture three and one-half inches and focal length equal to that of the large mirror, seventeen feet five inches, was fixed on the side of the main telescope tube. This small telescope, whose eye-piece is supplied with electrically illuminated wires, serves well its purpose of guiding upon moving objects. The original mechanism for moving the telescope slowly in declination by an observer at the upper end of the main telescope has been extended to the lower end, where it is within convenient reach of the observer at the eye-piece of the new guiding telescope.

A special room for silvering the mirrors has been constructed within the lower story of the Crossley dome, and a number of other minor improvements have been made.

All the walks, hitherto of wooden construction, have been replaced within the biennial period: the gently inclined walks with heavy planking, and galvanized iron pipe railings set in concrete; and the level walks with heavy concrete. Several new walks, joining frequented points, have been laid with concrete.

Prior to 1910 there were no restrictions as to driving over all parts of the summit unoccupied by buildings. A cement curbing, starting at the north end of the main building, running around the north and east sides of the meridian house, and thence to a point near the northeast entrance to the great dome, now limits vehicles to one definite narrow driveway near the north, east and south borders of the flat summit, and to the flat on the west side of the main building. All other free space on the summit has been graded with rich soil, and a good start on lawns has been made.

In the early months of 1909 and 1910, afforestation immediately around the summit was undertaken, in charge of Mr. WRIGHT, by planting acorns, of Mount Hamilton growth, and many hundreds of nursery trees one and two years old. The number of new trees living at the date of this report is disappointingly small, but the experience gained should be useful in guiding similar work, on a larger scale, in future years.

We are under great obligations to the Forestry Department of the United States for advice, and for liberal supplies of young trees.

It is scarcely possible for dwellers in ordinary locations to realize the difficulties of lawn-making and tree-growing on Mount Hamilton. The soil is thin and the drainage is perfect; there are no summer fogs and clouds; the air is of desert dryness; and the dryness is in effect accentuated by prevailing winds. New trees must be liberally irrigated through several summers, and especially during those months when the springs are running lowest. Reservoirs for the storage of the water surplusage of winter and spring must be the starting point in plans for lawns and trees.

In the summer of 1909 the Regents appropriated the sum of twenty-seven hundred dollars to erect a steel tank, of one hundred and sixty thousand gallons capacity, on Kepler Peak, to supplement the storage capacity of the brick and wooden tanks (160,000) already installed there. The heavy steel tank, on a carefully prepared foundation, was completed in September, 1909. Notwithstanding the shortage of rainfall in the past season, and the heavy withdrawal for irrigation, all the storage reservoirs were full on July 1, 1910.

The slopes immediately below the flat summit are composed of broken rock, dumped over the edge when the summit was leveled off, about the year 1880. Wherever this rock has disintegrated during the intervening thirty years, the native grasses and wild oats have obtained a foothold. It is planned to assist this process by throwing a light coating of soil, containing the seeds of these growths, over the more conspicuous of these slopes. It is believed that much can be done in this manner, and at little expense, to cover the forbidding rock slopes and slightly to reduce radiation effects in the atmosphere immediately surrounding the domes containing the telescopes.

The section of the overhead electric line running from the switchboard down to the Crossley dome suffered frequently and severely from the high winds of winter, and it was wrecked several times. This section was undergrounded in 1909, assistance to that end having been generously afforded by the Pacific Gas and Electric Company, of San Francisco, and by the Standard Underground Cable Company, of Pittsburgh, Pennsylvania. Service over this line has not been interrupted since the change was made. The overhead lines running eastward from the switchboard should be undergrounded, and it is hoped that this improvement may be afforded in the near future.

In August, 1909, the rates of the stage company, which supplied mail, passenger and freight service between San Jose and Mount Hamilton, were in effect more than doubled. In this emergency the passenger and freight service essential to the observatory and its people was supplied by our own wagons, mule team, and driver, from September 1, 1909, to July 1, 1910. Two round trips per week to San Jose were made.

The schedule of the horse stages has been lengthened from time to time during the past twenty years, but never shortened. In various ways the service grew poorer. One reason for this lay in the fact that travelers were growing tired of slow stages, and more visitors were coming to the observatory in automobiles than in carriages. When the Post Office Department requested bids for carrying the mails during the four-year period beginning on July 1, 1910, none were entered by horse stages. The department generously expressed a willingness to pay an increased sum, up to a certain limit, for an expedited automobile mail service. The subject was not easy of agreement, and it was feared for a time that the six day per week mail service must be reduced to a three day per week mail service. Fortunately, at the last moment, arrangements were made acceptable to the department and to the automobile stage company, and it is confidently expected that the automobile service for the mails, passengers and small freight will be thoroughly modern.

Many of the photographs secured at the Flint Island eclipse of January 3, 1908, have been submitted to careful study with interesting results.

It was feared that the rain in the five minutes immediately preceding totality had injured the photographs forming the basis of search for intramercurial planets, as the water got inside of the camera and ran across the dry plates in the plate holders. Dr. PERRINE compared the images of stars recorded on these plates with the charts of the same region of sky formed photographically at Mount Hamilton before the eclipse. The images of 506 stars were found on the Flint Island plates. Several of these are fainter than 9.0 visual magnitude, and a large number are between 8.0 and 9.0. From the distribution of the fainter stars on the plates it appears that the search was uniformly successful throughout the entire critical region, and that they suffered no detriment from the rain. In fact, the water-streaked areas on the plates recorded their quota of stars as faithfully as the unstained areas.

All the images were identified as known stars and planets. The taking of duplicate negatives covering the entire region enabled a definite decision to be made concerning other suspected images on any of the plates, and all such were found to be the usual and unavoidable defects in the films. These observations make it practically certain that there are no intramercurial bodies of 8.0 visual magnitude, or brighter, in or near the plane of the Sun's equator, with elongation distances of 12°, or less, as viewed from the Earth.

It has been shown by Dr. PERRINE that a planetary body of 8.0 magnitude in the region searched could hardly be more than twenty-five or thirty miles in diameter, and that it would require fully one million such objects as dense as *Mercury* to produce the observed disturbances in *Mercury's* motion. Considering this fact, and the greatly increased number of objects required if they should be one or two magnitudes fainter than the limit of our search, I think we may say that the intramercurial problem in its original significance is concluded as to its observational side. It would not be surprising if a number of small planets should be found on the occasion of future eclipses, but it is felt that these would be totally inadequate to supply the disturbing attractions upon the inner planets, which gave origin to the so-called intramercurial-planet problem.

Dr. AITKEN has continued the double star survey of the northern sky according to the systematic plans described in previous reports. Three hundred and eighty-five new double stars were discovered, in the biennial period, with the 36-inch refractor. The two component stars in every case are less than five seconds of arc apart. This survey as carried on at Mount Hamilton will extend to — 22° declination and include all stars as bright as 9.0 visual magnitude. Fully ninety per cent of the survey of the northern sky is now complete. The unobserved areas are in the winter sky. Given average winter observing conditions, I shall hope to note the completion of the survey in my next report. Thus far, 3,500 close double stars have been discovered, as one result of the survey: 1,300 + by Professor HUSSEY and 2,200 by Dr. AITKEN.

The problems of the stellar system cannot be regarded as solved unless they are based upon homogeneous observations extending over the entire sky. There is unanimity of opinion amongst astronomers that the Lick Observatory double-star survey, extending from the north pole of the sky to 22° south of the equator, should be extended on to the south pole of the sky as early as practicable, and that Dr. AITKEN is the logical man for this work. Given a first-class refracting telescope of from 20 to 27 inches aperture, at a good location in the southern hemisphere, four years of observing should suffice to make the survey complete. Careful consideration has been given to the subject of ways and means for accomplishing this purpose. Two practicable plans appear to be available. I describe one:

The government of the South African Union is constructing a well-equipped observatory at Johannesburg in the Transvaal. The principal instrument called for in the plans is the 26-inch refracting telescope now under construction by Sir HOWARD GRUBB. The maker has promised delivery early in the year 1911. Director INNES of the Johannesburg Observatory, with exceeding generosity, has offered the use of the 26-inch refractor, without charge, to Dr. AITKEN, in order that he may complete the Lick Observatory double-star survey. According to this proposal, Director INNES would use the telescope about three hours of each clear night and Dr. AITKEN the remainder of the night. There should be no special difficulty in securing funds to cover the expense of the expedition, and it is hoped that Dr. AITKEN may enter upon these plans immediately following the completion of the telescope.

It is scarcely necessary to repeat the truism that the great value of this splendid survey lies not in the discoveries of more double stars themselves, but in the increased opportunity which these discoveries will afford in the future study of double stars in particular, and of the structure of the stellar universe in general. For example: Utilizing the results in a small section of the sky, Dr. AITKEN has made a statistical study of the number and distribution of visual double stars and of the relations existing between the angular separation, the numbers and the magnitudes of the systems whose components are closer than five seconds of arc. He has found that the proportion of stars whose components are really close to each other is systematically smaller and smaller as he passes from brighter stars to fainter stars. This surprising result should, of course, be confirmed by studies based upon the double stars distributed over the entire sky as soon as the survey shall have been finished. We have here a mere suggestion of the fruits which must come out of the complete survey.

Dr. AITKEN has maintained his micrometer observations of a short selected list of well-known double stars which are in rapid orbital motion.

New orbits have been computed for the binary stars β 612, 55 *Tauri,* 4 *Aquarii,* and a preliminary orbit for π_2 *Ursæ Minoris.*

Dr. AITKEN observed the position of the two satellites of *Mars* with reference to the planet on five nights in September and October, 1909. The measures involved more than 2,700 micrometer settings. The eclipses of *Saturn's* satellites were observed on three nights.

The determination of the solar parallax, as derived from the photographs of *Eros* taken with the Crossley reflector in 1900, and measured here by means of a special grant from the Carnegie Institution of Washington during the years 1905-

08, was brought to a conclusion early in 1909 by Dr. PERRINE. Two methods of solution, essentially independent, led to the values 8″.0070 and 8″.0064. There was no apparent reason why one of these values should be given greater weight than the other, and the simple mean was adopted as the final result: *Solar parallax* = 8″.8067. Confidence is felt that this value must be near the truth, and as accurate as the original mounting of the Crossley reflector would permit us to obtain, especially as it was not possible to reach an essentially different value by any reasonable variation in the methods of combining the results for the different nights of observation. The work is undergoing publication by the Carnegie Institution.

When the spectrum of *Mars* was under observation on Mount Hamilton in 1894, for the purpose of detecting the presence of water vapor in the planet's atmosphere, I found that the water vapor in the Earth's atmosphere was, and is, the great obstacle in the way of success. I then resolved to repeat the observations from Mount Whitney, the highest point in the United States, when the planet would again come into position favorable for the purpose. At this elevation, 14,500 feet, about four-fifths of the vapor contained in the atmosphere should be below the observer, and but one-fifth above him. The planet would be favorably placed in August-September, 1909, when *Mars* would be near the Earth and high above the horizon at the time of the year when Mount Whitney could be ascended with instruments. Late in August, 1908, I ascended Mount Whitney, in order to determine the limiting sizes of the instruments which could be transported safely over the rocky trails on the backs of pack animals, and to plan the living arrangements for the proposed expedition of 1909. Director ABBOT of the Smithsonian Observatory accompanied me. Remaining on the summit throughout the night of August 24, 1908, we found low relative and absolute humidities, which promised well for the contemplated observations of the spectrum of *Mars*.

Before leaving the summit it was decided that observations in 1909, requiring residence of a week or more on the summit, should not be undertaken unless a building of some kind could be erected as a shelter in case of storm. The question was presented to Dr. WALCOTT, secretary of the Smithsonian Institution, and through his lively interest an appropriation was made from the Hodgkins Fund to provide a permanent stone, steel, and glass building containing three rooms for the shelter of the 1909 and future expeditions.

As soon as the shelter was assured, Mr. WM. H. CROCKER, Regent of the University of California, made generous provision for all of the expenses of the expedition from the Lick Observatory, including such pieces of new apparatus as were required to complete the equipment.

The members of the expedition were Director CAMPBELL, Assistant Astronomer ALBRECHT, and Carpenter HOOVER, of the Lick Observatory; Dr. MILLER, of San Jose, who cared for the health of the party; Professor ALEXANDER MCADIE, who was detailed by the chief of the Weather Bureau to accompany the expedition; Mr. W. L. SKINNER, of Lone Pine; and Mr. G. F. MARSH, of Lone Pine, who met us on the summit, he having completed the building on the morning of our arrival.

We were on the summit of Mount Whitney from August 28 to September 4, 1909. The atmospheric conditions were extremely favorable on the nights of September 1st and 2d, and successful photographs of the spectra of *Mars* and the Moon were obtained.

The conclusion drawn from the observations, in view of the extreme faintness and apparent equality of the water-vapor absorption bands in the Martian and lunar spectra, as observed at small zenith distances through a minimum of water vapor, is that the quantity of any water vapor existing in the equatorial atmosphere of *Mars* at the time these observations were made was too slight to be detected by available spectrographic methods. Recalling that the rays as photographed had passed from the Sun through the planet's atmosphere, for the most part down to its surface and out again to us, thus traversing the Martian atmosphere twice, and multiplying the absorptive effect, it is difficult to conceive that the quantity of vapor above unit area on *Mars* could exceed or equal the quantity of terrestrial water vapor above the same area on Mount Whitney.

In particular, it is not contended that *Mars* has no water vapor. The waxing and waning of the polar caps are usually considered as evidence of the existence of water vapor and snow on that planet, and this is the opinion which I have always held; but the quantity of vapor must be too slight for detection by the insensitive spectrographic method referred to.

There has been a disposition in certain quarters to say that the conditions on Mount Whitney were really not favorable for this purpose, because the observations were made in the summer season and the higher atmospheric strata of the Earth must have contained much water vapor. It need only be remarked that the evidences of water vapor absorption by the terrestrial and Martian atmospheres combined were exceedingly slight, and it should be apparent to everyone that the more vapor there was above Mount Whitney the less there could have been in the Martian atmosphere in order to produce the minute observed effect.

It is well known that several astronomers of a generation ago utilized the Doppler-Fizeau displacements of spectral lines to distinguish, in the observed solar spectrum, between absorption lines of truly solar origin and the absorption lines of water vapor and oxygen introduced by the earth's atmosphere. The approach of the eastern edge of the Sun toward the terrestrial observer and the recession of the western edge from him, displaced the lines of solar origin to the violet and red, respectively, from their normal positions, whereas the terrestrial lines remained in their normal positions.

It was realized by me as early as 1896 that the same principle could be applied in observing the spectrum of *Mars* for evidence of water vapor and oxygen absorption in that planet's atmosphere, provided the spectrum could be photographed with high dispersion; for when *Mars* is at or near quadrature with reference to the Earth, the two planets are relatively approaching or receding from one another, 20 kilometers per second, more or less, depending upon the concurrence of favorable circumstances. If the spectrum of *Mars* were photographed under these conditions, the absorption lines introduced by the Martian atmosphere and the absorption lines introduced by the Earth's atmosphere should be seen separate and side by side on the photographic plate. *Mars* was favorably situated for this purpose in January and February, 1910. A special high dispersion spectrograph was constructed, partly from Wm. H.

CROCKER funds, partly from funds granted by the Rumford Committee of the American Academy, and partly from university funds. The necessary observations of the Martian spectrum and the lunar spectrum for comparison were obtained in January, February, and March by Dr. ALBRECHT, who also measured the plates. The dispersion employed was such that the water vapor lines originating in our atmosphere and any originating in *Mars's* atmosphere should have appeared side by side, though not entirely separate. If the absorptions by the two planets were equal, the two sets of lines of equal intensities should, in effect, have appeared as broad lines of double width, and their centers should have been displaced by one-half of the relative velocity of the Earth and *Mars*. The facts are that the terrestrial lines were not bordered by Martian lines nor increased in width.

When the micrometer wire was set successively in the positions which Martian absorption lines would occupy, no traces of absorption were found in these positions. In fact, Martian absorption did not exist to such an extent as to be visible in the spectrum, nor to influence the measurements referred to. Similar results were obtained for the oxygen lines. The quantity of water vapor in the Martian atmosphere must have been small in comparison with that contained in the atmosphere above Mount Hamilton under the excellent conditions prevailing at the time of observation. Likewise, the quantity of oxygen above unit area on *Mars* must have been small in comparison with that above the same area on the Earth. It should be repeated that the rays of light utilized had passed, in effect, at least twice through the Martian atmosphere, thus multiplying any existing absorptive effects.

The return of Halley's Comet was anticipated with considerable interest, and preparations were made to secure series of observations, as complete as possible.

In the interval, September 12, 1909, to July 1, 1910, Dr. CURTIS obtained three hundred and sixty direct photographs of the comet on ninety-one nights. Two hundred and two of these were made with the Crossley reflector, one hundred and eighteen with 5-inch and 6-inch portrait lenses, and forty with small lenses whose ratios of aperture to focal length were unusually great. The four smaller cameras were mounted on the massive tube of the Crossley reflector, and great steadiness and accuracy in following were thus maintained.

It appears probable that our photographs of Halley's Comet form the most extensive series extant. They are of great interest now, and they should be of consummate interest seventy-five years later when the return of the comet is imminent. A large selection from the series should be made for reproduction; but here we encounter again the publication problem. The sum of six hundred dollars should be used for this purpose, and we hope that a way may be found to issue an exhaustive paper, completely illustrated, in one of our regular mediums of publication. Dr. CURTIS is making an extensive study of the plates; Mr. WRIGHT has valuable spectroscopic observations extending throughout the apparition of the comet; numerous observations of the tail were made by various members of the staff, especially when the tail was near the Earth; and the results of all of these observations should be issued in a manner worthy of the subject and occasion.

It is characteristic of comets' tails that they curve backward from the line drawn from the Sun through the nucleus, the degree of the lagging being a function chiefly of the comet's distance from the Sun. It was expected that the tail of Halley's Comet would lag behind the line joining the Sun and nucleus to a certain extent, in which case the Earth would pass through the tail of the comet on the night of May 18th. It transpired that the tail lagged behind much more than could have been anticipated, and that the Earth did not pass centrally through the tail. It is probable that we passed through the south side of the preceding edge of the tail. No unusual phenomena were observed in this connection.

On the nights preceding and following May 18, 1910, Halley's Comet was a magnificent spectacle as viewed through the clear atmosphere of Mount Hamilton.

An interesting study of Comet *c* 1908 was made by Miss GLANCY, Fellow, based upon photographic observations secured here by herself. This comet was the most active of any comet, as to transformations in the structures of its tail, since the application of the photographic dry plate to this subject. The comparison of photographs made on successive nights and in several cases of two photographs on the same night revealed in the clearest possible manner that the tail materials were traveling outwardly from the head, with high velocities, in response to some force or forces originating in the Sun, as required by essentially all recent theories of tail formation.

When this comet passed to the southern sky Dr. CURTIS, in charge of the D. O. Mills Expedition at Santiago, Chile, secured excellent photographs with large portrait cameras, which he had borrowed from Santiago photographers, thus extending the accurate historical record of this interesting object through several weeks.

The spectrum of this comet was likewise epoch-making. Observations obtained at Mount Hamilton and Santiago and at several other observatories brought to light an essentially new form of cometary spectrum, in that lines arranged in rhythmical pairs were given accurate observations. Professor FOWLER, of London, has since succeeded in matching this spectrum in his laboratory by light obtained electrically from rarefied carbon monoxide under certain conditions, but it has not yet been made clear why the spectrum of this comet should differ so widely from that of other similarly observed comets.

Micrometer observations of comet positions have been obtained as follows:—

Comet *c* 1908	8 nights	Miss GLANCY
Comet *a* 1909	7 nights	Miss GLANCY
Comet *e* 1909	5 nights	AITKEN
Comet *e* 1909	6 nights	YOUNG
Comet Halley	14 nights	AITKEN
Comet *a* 1910	5 nights	AITKEN
Comet *b* 1910	7 nights	YOUNG

Miss GLANCY made micrometer observations for the positions of the asteroids *Juewa* (139) on four nights and of *Athor* (161) on seven nights.

Accurate positions of comets were determined from Crossley photographic plates by Dr. CURTIS on twenty nights for Comet Halley and on three nights for Comet *a* 1910.

The excellent weather prevailing during the more interesting phases of Halley's Comet enabled Dr. AITKEN to secure on May 15th the last position observation prior to the transit of the comet's head across the Sun on May 18th, and on May 20th the first position observation following the transit, so far as published observations enable us to determine. These observations are of special value in connection with perturbations of the comet arising from its close approach to the Earth.

In the summer of 1908 Mr. FATH, Fellow, investigated the nature of the faint light which for many years had been noticed on summer nights along our northern horizon. Three hypotheses as to the origin of this light were examined: that it is an aurora; that it is a twilight arch; and that it is the Zodiacal Light. Sporadic observations of a similar nature had been made in earlier years by HERRICK, NEWCOMB, and BARNARD. It seemed fair to conclude from Mr. FATH's observations that the phenomenon is the Zodiacal Light.

The lenticular illumination of the sky, which we call the Zodiacal Light, can usually be traced east and west from the Sun, entirely across the night sky of Mount Hamilton and other good observing stations. This establishes that the materials which send the light to us are distributed approximately in the plane of the ecliptic, or of the Sun's equator, even further out from the Sun (east and west) than the orbit of the Earth. Mr. FATH's observations of the illumination above the northern horizon at midnight on fourteen nights established that the materials responsible for the Zodiacal Light extended northwardly from the Sun at least 46°, as viewed from the Earth.

These studies must be considered as merely preliminary. There is opportunity for an efficient organization of observers occupying selected observing stations in both hemispheres to obtain exceedingly valuable results as to the form and dimensions of the lenticular volume containing the Zodiacal Light, and of the variations in Zodiacal Light intensity as we proceed outwardly from the Sun. The subject is one of growing importance.

The spectrum of the Zodiacal Light was photographed by Dr. FATH in the fall of 1908 on Mount Hamilton, and in the fall of 1909 on Mount Wilson. The spectrum appeared to be a replica of the solar spectrum, in so far as could be judged from the faintness and small scale of the photographic image.

We here have strong evidence in support of the view that the Zodiacal Light is sunlight reflected from concrete particles distributed throughout the lenticular volume referred to.

The thesis of Mr. FATH, in partial fulfillment of the requirements of the degree of doctor of philosophy in the University of California, based upon the spectra of some spiral nebulæ and globular star clusters photographed with the Crossley reflector, was a successful beginning in the study of an important subject. The spectra of the spiral nebulæ are described in the text-books as continuous. Mr. FATH found that no spiral nebula investigated has a truly continuous spectrum. They vary from spectra consisting principally of bright lines, such as are found in the gaseous nebulæ, to those containing only absorption lines of the solar type. These objects appear to occupy early places in the evolutionary development of stars and the stellar system, and the investigations should be continued on a more extensive scale.

The spectrum of the great cluster of stars in *Hercules* gave evidence of containing stars of different spectral types, while two other clusters recorded spectra of the so-called F type, or the type which is believed to indicate average effective age. A spectrogram of the great nebula in *Andromeda,* of excellent density, reveals a type apparently identical with that of our Sun. It is difficult to interpret this observation, except upon the theory that this, the most prominent nebula in the whole sky, is in reality an extremely distant aggregation of stars whose processes of evolution have reached the solar stage.

The thesis of Mr. DUNCAN, Fellow, in partial fulfillment of the requirements of the degree of doctor of philosophy in the University of California, studied the orbits of the *Cepheid* variable stars Y *Sagittarii* and RT *Aurigæ,* and the possible causes for this type of stellar variation. The orbits deduced for these two stars, from spectrographic determinations of their radial velocities, confirmed the remarkable fact first announced in Dr. ALBRECHT'S thesis, that the stars of this class have maximum brilliancy at the time of their most rapid approach to the observer, and minimum brilliancy at the time of their most rapid recession from the observer; in other words, that the brilliancy of a variable star of this class at any instant is a function of the observer's position in space. Mr. DUNCAN discussed several hypotheses to explain the variations of brilliancy, but it must be said that no thoroughly satisfactory explanation has yet been presented.

The appointment of Astronomer PERRINE to the directorship of the National Observatory of the Argentine Republic, and his departure in April, 1909, necessitated several changes in our observing staff. Dr. HEBER D. CURTIS, in charge of the D. O. Mills Expedition at Santiago, Chile, was called back to Mount Hamilton, to succeed Dr. PERRINE in charge of the Crossley reflector and in other duties. Assistant Astronomer JOSEPH H. MOORE was appointed acting astronomer in charge of the D. O. Mills Expedition. The latter left Mount Hamilton in April, 1909, and assumed charge of the expedition on June 10, 1909. Dr. CURTIS returned to Mount Hamilton on August 22d.

The second period of the D. O. Mills Expedition, in immediate charge of Dr. CURTIS, extending from March 1, 1906, to June 10, 1909, was characterized by most commendable activity. The number of photographs of stellar spectra secured in this interval was approximately sixteen hundred; all of these were measured in a preliminary way and a large proportion of them definitively; Comet Morehouse, especially interesting from the unusual changes in the structure of the tail and as to its spectrum, was studied on many nights; and Dr. CURTIS took an active part in the Pan-American Scientific Congress of 1908-09, presenting one general and two technical papers on astronomical subjects.

The high standards set by Astronomers WRIGHT and CURTIS, successively in charge of the expedition, have been maintained by Acting Astronomer MOORE. The number of spectrograms secured from June 10, 1909, to July 1, 1910, was nearly nine hundred. The duties of Mrs. MOORE, assistant, have related to the measurement of the spectrograms, and the measures and reductions have almost kept pace with the observations.

The faithful services of G. F. PADDOCK, assistant astronomer, throughout the administrations of Messrs. CURTIS and MOORE should be acknowledged. An assistant to measure the plates was not employed during the second period of the expedition, and the measures were necessarily in arrears. Messrs. CURTIS and OLIVIER have devoted a proportion of their time at Mount Hamilton to the measures and reductions. It is a great satisfaction to say that all the southern spectrograms secured up to the end of the year 1910 will have been measured and reduced by that date.

The total number of spectrograms secured at Santiago during the three administrations up to July 1, 1910, was 3,384. The total number of stars observed is 710. With a few exceptions these are all south of declination — 20°. The accuracy of the resulting radial velocities of the stars is fully up to present-day standards.

The solution of the larger problems of the sidereal system is demanding that the spectrographic observations of stellar velocities be applied to as many stars as the light collecting powers of existing telescopes will permit. The D. O. Mills Expedition is fitted to secure these observations, rapidly, and with remarkable economy. Funds pledged by the late Mr. MILLS are sufficient to maintain this work only until the spring of 1911. It is hoped by astronomers in all countries, as well as by those of us immediately concerned, that the life of the expedition may be extended at least five years, or, if possible, that endowment will be available for obtaining results in perpetuity. To have the work cease next year would be a pity.

The most extensive investigations in progress at Mount Hamilton relate likewise to the spectrographic determination of stellar velocities by means of the D. O. Mills spectrograph attached to the 36-inch refractor, in accordance with the program entered upon by Mr. CAMPBELL in 1896. The spectrograms secured on this program during the biennial period are numbered from 5,318 to 6,529. Approximately one thousand stars all north of declination — 30° have been observed in this manner. The observing program, as finally made, definitely includes all stars brighter than 5.01 visual magnitude, as assigned in the Revised Harvard Photometry, lying in the north three-quarters of the sky; and it is planned to secure at least four observations of each star, except for those stars whose spectra are found to contain no measurable lines. The observations of the latter will be deferred until after the completion of the remainder of the program, when dispersion lower than that of 3-prisms will then be employed upon these stars; and, as the exposure times will be short, this supplementary program should be completed rapidly. The observing program is essentially complete for all stars accessible for summer observation. A small section of the winter sky is in arrears; but given the average number of clear nights next winter the remaining observations should be secured. Largely by virtue of assistance supplied by the Carnegie Institution of Washington, the measures and the reductions of the photographs are nearly up to date.

The total number of stars observed at Mount Hamilton and at Santiago, not counting twice those observed at both stations, is more than sixteen hundred.

The number of stars whose radial velocities are variable, under the influence of invisible companion stars, continues to increase. Twenty-five systems of this kind have been announced from Santiago and fifty-three systems from Mount Hamilton during the two years. More than fifty additional binary systems have been discovered at the two stations, and are awaiting announcement later in the present year.

Many of the stars which have been under observation at Mount Hamilton during the past ten or twelve years, which were thought to be traveling with constant speeds, are now found to be moving with variable radial velocities in orbits of long periods.

More than four hundred spectrographic binary systems have been discovered in the past fifteen years, principally by the Mills spectrographs at Mount Hamilton and at Santiago, and by the Bruce spectrograph at Williams Bay, out of not more than seventeen hundred observed stars. Thus one star in four, approximately, of those previously supposed to be single is proved to be a close double, the invisible companion in each case being of nearly the same order of mass as the primary star. The proportion is rapidly increasing, and as the observations are extended over a longer period, enabling us to detect variable velocity in the case of slowly revolving systems, we must expect that at least one star in every two or three is a spectroscopic binary. In fact, the star whose radial velocity is constant, indicating that it is not attended by a massive close companion, may be the exception and not the rule. Indeed, it would not be surprising if our solar system, consisting of a great central Sun and a family of very small planets, should prove to be not the prevailing type of stellar systems, but an extreme type. In this connection we should note the total absence of evidence that any other star is attended by planets comparable in minuteness with the planets of the solar system.

Up to January 1, 1910, the radial velocities of 1,020 stars had been determined with the Mills spectrographs at Mount Hamilton and at Santiago, after excluding stars whose spectral lines did not admit of accurate measurement, several other stars whose deduced velocities depended upon a single observation, and those spectroscopic binary systems for which the velocities of the centers of masses had not been determined. Published velocities were available also for forty stars observed with spectrographs at other observatories and not yet observed with the Mills spectrographs. Adding the velocities for thirteen nebulæ, as obtained in 1890 by KEELER, using visual methods, there were 1,073 radial velocities available for the preliminary solution of certain fundamental problems of the stellar system. With the assistance of my colleagues, the computations for these solutions were made prior to January 20, 1909; and below are given the leading results, in outline, as they were presented in the Silliman lectures delivered in Yale University between January 24 and February 2, 1910. Lack of space prevents the quoting of details.

Assuming that the apparent radial velocity of each star was the reflex of the Sun's motion through space, and giving equal weight to each of 1,047 objects, a solution of the 1,047 resulting equations by the method of least squares assigned a speed of 17.73^{km} per second to the solar system, toward that point in the sky whose right ascension is $273^\circ.5$ and declination $+ 28^\circ.0$.

Another solution was made by combining the 1,047 stellar velocities into 172 groups and solving the 172 resulting equations. The deduced motion of the solar system was at the rate of 17.77^{km} per second toward that point in the sky whose right ascension is $272^\circ.0$ and declination $+ 27^\circ.5$.

It is expected that a more definitive solution will be made next year, and no doubt these elements obtained for the solar motion will be slightly altered.

After the effect of the solar motion upon the apparent motion of each star was eliminated, the velocities of the stars were tabulated with reference to their spectral types. The results were as follows. The letters O and B represent stars in the early stages of evolution, and M the oldest stars.

No. of Stars.	Spectral Types.	Average Velocities.
141	O and B	8.99^{km}
133	A	9.94
159	F	13.90
529	G and K	15.15
72	M	16.55
13	nebulæ (KEELER)	23.4

The number of nebulæ is entirely too small to make the result trustworthy for them, but in the first five lines of the table we have the remarkable discovery that the speed of a star in space is a function of its spectral type: new stars move slowly and old stars move relatively rapidly. It appears that the velocity of a star increases as it grows older. It is difficult to conceive that stellar velocities should vary otherwise than in accordance with the law of gravitation, each star moving under the combined attractions of all the other stellar systems in the universe, but it is not clear why the velocities should in general increase with time.

KAPTEYN discovered six years ago that the stars have a preference for motion toward and from two opposite points of the celestial sphere: one of the points being in right ascension 93° and declination + 12°. His determination was based upon the observed proper motions of stars. A half dozen confirmations were promptly published by other astronomers, basing them also upon proper motion data. Our radial velocity determinations afforded an admirable test of KAPTEYN's conclusion. If the stars are moving at random, the average velocities of approach and recession should be equal in all parts of the sky. If the stars have a preference for motion in the directions assigned by KAPTEYN, the velocities of approach and recession should be greater in the vicinity of the two points defined by KAPTEYN than in areas intermediate between these two points. I found that 154 stars lying within 30° of KAPTEYN's points have an average radial velocity of 15.9^{km} per second; that 383 stars lying in the zones 30° to 60° from these points have average radial velocities of 14.0^{km} per second; and that 508 stars situated in the zones 60° to 90° from these points have average radial velocities of only 12.75^{km} per second. It was therefore found that the average radial velocities near KAPTEYN's points are approximately thirty-three per cent greater than the average velocities of the stars situated midway between these points. KAPTEYN's conclusions were confirmed.

The radial velocities of the stars permit us to determine the average distances of large classes of stars, though not of individual stars. Computations to this end, while highly preliminary, led to interesting conclusions.

The view had prevailed that early-type stars were further away from our position in space than are the older stars. KAPTEYN's results, for example, placed the early-type stars approximately two and a quarter times as far away from us as the older-type stars. My results do not confirm this conclusion. It is found that the stars of different spectral types are in general quite thoroughly mixed.

It was found that all classes of stars down to the fifth, and especially the brighter magnitudes, were further away than the formulæ for average distances had placed them; that is, that the scale of the sidereal universe is greater than had previously been supposed.

More complete solutions of the problems referred to, which are but a few of those resting quite directly upon our observational results, will be undertaken in the near future, when the observational data shall have been rendered more homogeneous by the completion of the program.

A systematic study of spectroscopic binary stars led to many interesting conclusions. A few of these, in brief, are:—

First, the period of revolution in a binary star is a function of the spectral type: the periods for early types are in general short and for later types in general long.

Second, the eccentricity of the orbit is a function in general of the periods of revolution and, therefore, of the spectral types: the orbits of the short-period, early-type binaries are in general nearly circular, whereas the orbits of the long-period, late-type binaries are in general very eccentric.

The orbits of about seventy spectroscopic binary systems available at the time that the photographs were made seem to afford confirmation of the theoretical conclusions of DARWIN, POINCAIRE, and SEE concerning the origin and development of binary stellar systems.

Lick Observatory Bulletin No. 181, forming a Second Catalogue of Spectroscopic Binary Stars, lists all spectroscopic binaries discovered prior to January 1, 1910, and all orbital data available on March 15, 1910, and contains the report of my studies of spectroscopic binaries just described.

Dr. MOORE computed the orbit of the Cepheid variable X *Sagittarii.*

Mr. MERRILL computed the orbit of the spectroscopic binary *β Capricorni.*

Dr. CURTIS observed at Santiago the radial velocity of the star Córdoba Zones, $5^h.243$, whose proper motion is the largest known and found that it was receding from our solar system with an unprecedented speed of 242^{km} per second.

Mr. OLIVIER, Fellow, has utilized time spared from other duties for the discovery and measurement of double stars south of the southern limit of the Lick Observatory double-star survey. He discovered and measured forty-four pairs, and obtained several hundred observations of double stars already announced.

Mr. OLIVIER'S special interest has lain in the observation and study of meteors. He has charted 1,223 in the last year, and has computed the orbits of all for which the observational data are satisfactory.

Mr. WRIGHT studied the bright hydrogen lines in the spectrum of the variable star *Omicron Ceti,* in order to determine whether the multiple character of these lines is due to the action of magnetic forces in the star, in accordance with the phenomenon known as the Zeeman effect. He obtained no evidence of this effect.

Mr. WRIGHT is making systematic studies of the spectra of nebulæ and of various stars whose spectra contain bright lines, taking advantage of recent advances in photography to record the spectra in the yellow, orange, and red regions. A number of new nebulæ lines and stellar bright lines have been discovered in this manner.

The Rumford Committee of the American Academy of Arts and Sciences has made grants of funds to provide a Hartmann photometer, to be used in the study of polarized light in the solar corona as based upon photographs of the corona obtained by the Crocker eclipse expeditions; and to provide a quartz spectrograph for general utility in the study of celestial spectra in the ultra-violet. Both instruments are now utilized for the purposes specified, the former by Mr. YOUNG and the latter by Mr. WRIGHT.

A considerable number of minor studies by various members of the staff are not mentioned from lack of space.

The resignations of Astronomer PERRINE and Assistant Astronomer ALBRECHT to accept, respectively, the positions of director and first astronomer in the Argentine National Observatory, were recommended for acceptance with regret. Their services were exceedingly efficient. Confidence is felt, however, that their efficiency will assist in the development of astronomy in the southern hemisphere, and in removing arrears in the special lines of investigation for which the observatory at Córdoba is equipped. It is of interest to note that nine astronomers, who have been connected with the Lick Observatory, have recently spent several years in southern hemisphere astronomy, or have accepted permanent duties in the southern hemisphere. It is unavoidable that some disorganization should result from these frequent changes, but the end in view is worth the cost.

Dr. AITKEN was lecturer in the summer session of the university for the years 1908 and 1909.

Director CAMPBELL was Silliman lecturer in Yale University for the academic year 1909-10. He delivered eight lectures on the subject "Stellar Motions," with special reference to stellar motions as observed with the spectrograph.

The Janssen Prize of the Paris Academy of Sciences, consisting of a gold medal, was conferred upon Director CAMPBELL in the spring of 1910.

The director is pleased to acknowledge again the cordial support of all the members of the staff, and to express appreciation and thanks to those members of the staff who have assisted him in securing and measuring stellar spectrograms.

Respectfully submitted, W. W. CAMPBELL,
Director of the Lick Observatory.